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JUL 17 1996

In the Matter of

Advanced Television Systems
and Their Impact Upon the
Existing Television Broadcast
Service

MM Docket No. 87-268

FIFTH FURTHER NOTICE OF PROPOSED RULE MAKING

Adopted: May 9, 1996

Released May 20, 1996

Comment of:

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Submitted July 10, 1996

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EXECUTIVE SUMMARY

We appreciate the valuable contribution made to the advancement of digital television and related technologies by the Federal Communications Commission, its Advisory Committee on Advanced Television Services, and the Grand Alliance. In the end, we hope this will benefit U.S. citizens in a variety of ways.

The Commission can help ensure this will happen by adopting a less complex and costly progressive scan version of the proposed Grand Alliance standard. Based on our prior work on consumer preferences, as well as an engineering cost model developed at MIT described in the attached paper and the more comprehensive thesis on which it draws, we conclude that:

- * Interoperable (i.e., progressive scan) digital television sets, VCRs, and camcorders will be less expensive if they do not also have to be capable of receiving or originating both progressive scan and interlaced formats of digital television.
- * Interoperable digital television sets will be more useful to consumers.
- * Interoperable digital television production and broadcast equipment including high resolution cameras will also be less expensive and more useful.
- * Other markets, such as those for multimedia personal computers and workstations, or cable television head-end equipment, will also benefit as more useful products and services help create new applications of digital television technology.

Therefore,

The FCC should adopt a streamlined version of the Grand Alliance standard, to reduce costs and increase the benefits of digital television for consumers. Failure to simplify the standard by eliminating the unnecessary complexity of interlace will cost consumers billions of dollars.

INTRODUCTION

The attached article, "Modeling the Economics of Interoperability: Standards for Digital Television," was recently published in a journal of industrial economics. With our co-author, Bruce A. Jacobson, who wrote the thesis the article is based upon, we modeled the markets for interoperable and non-interoperable television displays, personal computers, broadcast equipment, and workstations. The thesis included analyses of camcorders and VCRs as well.

THE UNACCEPTABLE COSTS OF INTERLACE FOR CONSUMERS

Based on this research and related studies, we are convinced that consumers as well as producers will benefit from the greater interoperability of a progressive scan digital television standard. Failure to streamline the Grand Alliance standard by eliminating the costly and unnecessary interlaced formats will cost consumers billions of dollars. Interlace may cause even more harm than we forecast: it may in fact doom the whole enterprise to failure:

- * Japan introduced an interlaced HDTV system which failed in the marketplace;
- * Europe introduced an interlaced HDTV system which failed in the marketplace;
- * There is no reason to believe that the Grand Alliance standard will not meet a similar fate - unless it is improved by eliminating interlace.

THE CONSUMER BENEFITS OF PROGRESSIVE SCAN TELEVISION

The Commission can help ensure this will happen by adopting a less complex and costly progressive scan version of the proposed Grand Alliance standard. Based on our prior work on consumer preferences, as well as an engineering cost model developed at MIT described in the attached paper and the more comprehensive thesis on which it draws, we conclude that:

- * Interoperable (i.e., progressive scan) digital television sets, VCRs, and camcorders will be less expensive if they do not also have to be capable of receiving or originating both progressive scan and interlaced formats of digital television.
- * Interoperable digital television sets will be more useful to consumers.
- * Interoperable digital television production and broadcast equipment including high resolution cameras will also be less expensive and more useful.
- * Other markets, such as those for multimedia personal computers and workstations, or cable television head-end equipment, will also benefit as more useful products and services help create new applications of digital television technology.

RECOMMENDATION FOR FCC ACTION

The FCC should adopt a streamlined version of the Grand Alliance standard, to reduce costs and increase the benefits of digital television for consumers. Failure to simplify the standard by eliminating the unnecessary complexity of interlace will cost consumers billions of dollars.

CONCLUSION

The digital imaging technical community, publishers, medical professionals, film and television producers, several broadcasters, and last but not least, the computer industry agree that the Grand Alliance standard, if adopted in its entirety, will not serve their needs. Mandating such a specific definition of the contents of a digital bit stream would likewise harm consumer and producer interests. The damage may be limited, however, since consumers and producers will likely shift their attention entirely to more flexible computer network-based approaches to digital media. Speculation on the social consequences of the Commission's accelerating the abandonment of broadcast television by its actions are beyond the scope of these comments, but should be weighed by the Commissioners in their deliberations on this matter.

APPENDIX

McKnight L., J. Bailey, and B. Jaconson. "Modeling the Economics of Interoperability: Standards for Digital Television." Revue D'Économie Industrielle. Number 75, Trimester 1, 1996, pp. 187 - 210.

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MODELING THE ECONOMICS OF INTEROPERABILITY: STANDARDS FOR DIGITAL TELEVISION

Mots clés : Normes, interopérabilités, multimédia en réseau, télévision digitale, haute définition, télévision avancée, vidéo digitale

Key-words : Standards, interoperability economics, networked multimedia, digital television, HDTV, Advanced Television, digital video

INTRODUCTION

Standards development for digital television is an example of the changing way telecommunications standards are made. Part of this change is due to the commonality of the underlying technologies of communications, consumer electronics, and computers. In the future, it will become harder to tell the difference between a television and computer display, a camcorder and video telephone. (1)

(*) This article is based upon Jacobson (1993). The authors thank Robert Cohen, Steve Downs, Branko Gerovac, Jerry Hausman, Petros Kavassalis, Suzanne Neil, W. Russell Neuman, William Schreiber, Richard Solomon, David Staelin, Robert Stone, and David Tennenhouse for their contributions. Support for this research has been provided in part by the Advanced Research Projects Agency grant number.

(1) Pool (1983) describes this phenomenon as a "convergence of modes." Other scholars including Bove (1992), Schreiber (1990), Schnurr (1987), Hugenholtz (1987) and Scherer (1987) have analyzed technical and legal implications of this convergence.

With convergence, digital television may follow two models of standard setting consistent with the analysis by Kavassalis and Solomon (1996). The first model would be the systems model whereby each technology adopts their own standards and components. We define this as the non-interoperable scenario. If the benefits of convergence are realized by the manufacturers, it is possible that they may reach the next model for standards setting – the intermodal model. We call this the interoperable scenario. Both scenarios are possible for development of digital television standards. In this article, we quantify some of the economic differences between them and demonstrate some of the economic benefits realized by achieving adequate interoperability through standards setting.

An opportunity exists to define a standard for an open, interoperable digital television architecture flexible enough to meet a wide variety of needs across different industries. Interoperability for advanced television was defined by the Society of Motion Pictures and Television Engineers (SMPTE) as :

- the use of common standard components to serve diverse needs across all affected industries. A digital image architecture should enable the movement of image data across application and industry boundaries without image degradation and with minimum complication. This characteristic is called *interoperability*. (2)

The SMPTE definition of interoperability is applied in the models represented in this article.

This article argues that open standards promote interoperability which, in turn, lead to economic benefits. Open standards allow multiple vendors manufacturing similar products to realize learning effects from each other. While this may not be desirable to a digital television manufacturer because it may reduce their competitive advantage, this article presents a model where it will benefit *multiple industries* in the number of products sold and the average cost of those products. Most objections to a digital television architecture are raised for economic rather than technical reasons. Some argue that the manufacturing expense of including interoperability in digital television equipment – particularly receivers – will make an already costly unit prohibitively expensive. Such a standard, they argue, would destroy the market for HDTV receivers and doom the prospects of other digital consumer video equipment as well. (3)

- (2) SMPTE Task Force on Digital Image Architecture (1992), p 1. Foremost among SMPTE's goals is ensuring that a future digital image architecture enables an open system made up of functional modules with standard, public interfaces. In addition to SMPTE, the Information Infrastructure Task Force, FCC, NIST, ITU, IEEE, National Research Council, the U.S. Congress, and other organizations have taken steps in the 1990s in support of these goals. See, for example, U.S.A. (1992).
- (3) Documents critical of the notion of interoperability are difficult to find because as one expert asserted «well considered analysis disputing interoperability is impossible.» However, opposition to interoperability has frequently surfaced at working party meetings of the Federal Communications Commission's Advisory Committee on Advanced Television Service (ACATS) and the Advanced Television Systems Committee (ATSC) See Schreiber (1993).

To date, there has been little attempt to quantify the costs of an open, interoperable digital television architecture. This article addresses this issue by modeling the effects of interoperability on six different digital television markets. These markets are broadcast television, cable television, displays (HDTVs), video cassette recorders (VCRs), personal computers and workstations. Model assumptions and the structure of each industry segment are first described followed by model results, sensitivity analysis and conclusions.

The primary hypothesis of this article is that equipment with interoperable components will, in the medium and long run, provide benefits to component manufacturers through enhanced economies of scale and scope and to service providers through new business opportunities. The model shows interoperability would allow a chip that decompresses video signals to be used in both a workstation and an HDTV set, thus significantly increasing the size of the chip manufacturers' market. A chip manufacturer would traverse the experience curve more quickly than would otherwise be possible, resulting in a reduction of manufacturing costs.

This article models digital television standards (including HDTV) for both the interoperable and non-interoperable scenario. It shows that an open, interoperable digital television platform is critically important to realize the economic benefits of these new technologies. (4) Public policy makers, researchers, and business leaders in Europe, Asia, and the Americas have taken the first steps to capture these benefits. Further steps are needed, we conclude, including the adoption of an open standard to make data streams universally self-identifying. (5)

The modeling is done on the United States market, but the general pattern of significant benefits from adoption of an interoperable digital television architecture should hold in other nations as well. The abandonment in Europe in 1993 and Japan in 1994 of active government support of obsolescent analog, interlace High Definition Television systems provides the world with the opportunity to collaborate to develop an open communications infrastructure.

We recognize that development of new services and applications markets, software design, production, and internetworking issues are also important in determining the costs and benefits of interoperability for digital television and networked multimedia. We will extend the model to incorporate these and other factors in future work.

(4) Digital television is a term signifying digital video applications for education, health care, defense, entertainment, manufacturing, and commercial markets. Most attention to date has focused on HDTV, the home entertainment high resolution system market.

(5) SMPTE Header/Descriptor Task Force (1992) and Gerosac (1994).

I. – A MODEL OF INTEROPERABILITY

A major stumbling block to agreement on standards for interoperability is the presumed added cost to equipment and applications. (6) The economic model outlined in this article demonstrates that an interoperable HDTV standard actually enables production of equipment that is less costly than non-interoperable equipment over a fifteen year period. The model assumes that shared components, despite their possibly greater initial expense, ultimately create cost savings for equipment manufacturers. These cost savings can reduce consumer prices and thus result in increased sales of equipment.

The model quantifies the cost of interoperable and non-interoperable equipment for six markets. (7) These markets were chosen for several reasons :

- They are expected to be early adopters of digital television technology, as providers and consumers.
- The potential volume of sales for a particular digital television market is substantial enough to affect the cost of a product in a related market.

The first market analyzed is broadcast television. Currently, approximately 1500 broadcast television stations operate in the U.S. The model considers the transition costs of an average station as it acquires the capability to transmit and then produce high definition television programming. (8) The costs of this average station are scaled up as all broadcasters convert to digital television, taking into account that as more stations buy equipment and digital technology advances, the cost of that equipment decreases. Consideration of the FCC timetable for transition to HDTV is critical to estimating the timing of costs and benefits for this segment and is extended to other segments for ease of analysis

The second television segment represents the cable TV industry. Approximately 59 percent of television households in the U.S. subscribe to cable TV. U.S. cable TV subscribers currently number 55.1 million. 11,000 operators provide them with service. The transition costs to digital television are considerably less for the cable industry than for broadcasters. Therefore, some believe that cable providers may introduce HDTV programming before conventional broadcasters and lead the growth of the market for digital

- (6) Interoperability may also increase competition, threatening firms' market position by limiting the benefits of control of proprietary technologies. Interoperability may therefore be resisted by «incumbents» for competitive reasons.
- (7) This work builds on work done by Cohen (1991) and McKnight, et. al. (1992). An additional consumer electronics market, the camcorder, is addressed in Jacobson (1993).
- (8) One would expect, in practice, that successful stations in large markets would invest more in new equipment than less successful stations in small markets; for the purposes of this preliminary model, these differences are ignored. Testimony by Richard Solomon (1989) suggests that the transition costs to HDTV for all the nation's broadcasters would be approximately \$3 - \$10 billion. Solomon (1989) also stated that other estimates have ranged up to \$16 billion.

television. (9) The costs for cable TV operators are considered on a per-subscriber basis. The model estimates the cost to each subscriber who selects digital television cable service. The penetration of digital television cable TV is then used to scale up these costs.

Direct broadcast satellites are perhaps most capable of introducing nationwide HDTV service quickly, but are not modeled in this article.

The digital television display (i.e. HDTV) and the digital television VCR markets are important barometers of the adoption of digital video equipment by the general public. A total replacement of current television broadcasting equipment by its digital television equivalent will take many years, and will be influenced by many factors including the trade-off between equipment price and viewer preference for digital television. Other factors include the availability and variety of digital television programming, and the extent to which consumers value and are able to take advantage of interoperability. The model calculates the cost of producing an individual piece of digital television equipment and then estimates the annual penetration of digital television equipment by this industry segment as a function of cost.

The last two markets examined by this article is the personal computer and workstation markets. Only recently have these products been able to deliver full-motion video images. However, the introduction of multimedia products and services (e.g., MPEG and Quicktime digital video) suggest that digital television is close at hand.

Economic approach

The model is based on two premises. The first is that accumulated production of equipment results in systematic decreases in cost. Accumulated production of components (used in the manufacture of equipment) results in decreases in component cost ; consequently, the cost of the equipment produced from those components decreases. We believe this assumption is not unreasonable since it is supported by the historical record of cost declines in the electronics industry. (10) The rapid declines in computer prices are attributable to these experience efficiencies. In the context of our model of interoperable digital television, the components affected by and supporting interoperability can be used by all six markets ; those unaffected by interoperability are used only by single industries. Therefore, the market for the former will be larger than the market for the latter : interoperable components have greater accumulated production and thus decline in cost faster than non-interoperable components

The model is designed to determine equipment costs and production of digital television units for the first 15 years following the FCC designation of

(9) Green (1993).

(10) Hax (1982).

a terrestrial broadcast HDTV standard (estimated to be 1997). The model quantifies the benefit of an interoperable standard resulting from this process versus a non-interoperable standard.

The model assumes that interoperability can be achieved by adding functionality to the signal processing components and software of the equipment. By definition, interoperable signal processing components – which control and manipulate the digital data stream – can be used in equipment across many industries. This hypothesis is modeled as follows : suppose a non-interoperable HDTV initially costs \$1300. Converting this piece of equipment to one that supports interoperability would affect 30 percent of its components. Those components suffer a cost penalty of 25 percent due to the added complexity of supporting interoperability. Thus, a hypothetical HDTV incorporates two kinds of components : those whose cost is not increased by interoperability (i.e., the power supply, the chassis, the cabinet, the picture tube) and which cost \$910 (\$1,300 x 70 percent), and those interoperable parts (i.e. MPEG encoder/decoder, other electronics) which cost \$487.50 (\$1,300 x 30 percent x 1.25). In this example, the total cost of an interoperable HDTV would be \$1,397.50.

Modeling assumptions

To forecast the relationship between increased sales and cost benefits, we use the concept of an experience curve. The experience curve quantifies many benefits to increasing production quantity : learning, specialization and redesign of labor, product and process improvements, methods and systems rationalization, economies of scale, and organizational “tune-up.” (11) For example, Fig. 1 shows a 70% experience curve that is also defined by the following equation :

$$C_i = C_0(P_i/P_0)^{-a}; \text{ where}$$

C_i = unit cost in period i , and

P_i = production volume in period i

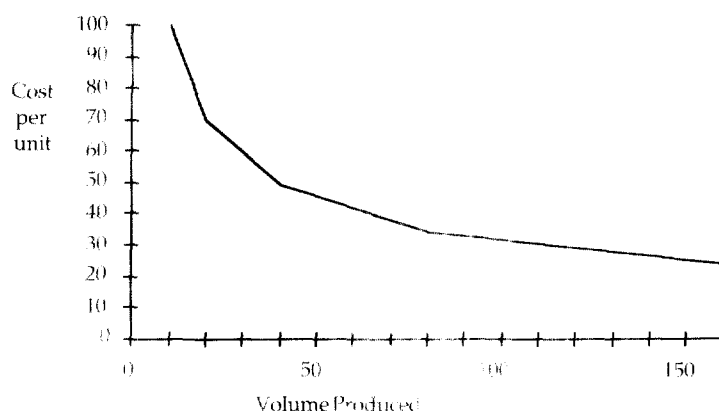
From the definition of the experience curve, we realize there is a cost savings with a doubling of the cumulative number of items manufactured. In our 70% experience curve example, this means that $C_i/C_0 = 0.70$ given that $P_i/P_0 = 2$. Therefore, $a = 0.515$. The 80 – 90% experience curves are conservative assumptions for the six markets modeled, we believe, given historical trends in the electronics industries

For our model we identify an experience curve for each of the six industry segments. There is one aggregate market for integrated circuits in the interoperable case which exhibits a 70% experience curve. (12)

(11) *ibid.*

(12) *ibid.*

FIGURE 1 - The 70% experience curve



As the market for digital television equipment grows, the cost of producing that equipment and the price paid by the consumer for that equipment will both decrease. Obviously, the experience curve implies that both non-interoperable and interoperable parts will decrease in price as a function of accumulated production. However, because the market for interoperable parts spans several industries, the accumulated production of these parts is much greater than that of non-interoperable parts, so, the annual percent decrease in cost of interoperable parts is greater than that of non-interoperable ones. Despite the initial penalty for complexity, interoperable products overtake their non-interoperable counterparts within a few years so that interoperable equipment costs less to produce.

The model estimates an additional effect of interoperability. As a result of decreasing price, the demand for interoperable equipment will be greater than the projected demand for non-interoperable equipment. Conversely, the initial cost increase of interoperable equipment reduces demand for that equipment. The model calculates the percent increase or decrease in demand by comparing the cost of the interoperable equipment with the cost of the base case non-interoperable equipment. Price elasticities are used to determine the increase or decrease in sales between the two cases based upon published estimates of price elasticities in the various markets.

Limitations of the model

Since the model presented in this article strives to assess quantitative measures for future equipment sales and cost, there is an inherent uncertainty associated with the results. (13) There are three variables common to all segments, which can be varied in a systematic way: the percentage of parts affected by interoperability, the cost penalty of those parts, and the rate at

(13) For a complete table of results from the sensitivity analysis, see Jacobson (1993).

which the cost of interoperable parts declines as a function of volume. One at a time, each of these variables was varied around the scenario norm to observe the sensitivity of the model to the change. The results of this analysis can be found in section IV, Analysis of results.

We also note that convergence enhances the interoperability across the different market segments, but makes it more difficult to label them. It becomes more difficult to categorize technologies as they converge and perform multiple functions. The introduction of computers incorporating televisions in 1994 demonstrate hardware which may be categorized as a computer or a television. While multi-function equipment may reduce overall sales (e.g. a consumer buys a multi-function workstation to do computing and watch television), this scenario is not explored in this article. It is impossible today to be certain of how future consumers and producers will conceive of the most salient attributes of their multi-functional products. The model therefore simply represents the more significant digital television markets that may exist according to the market structure of today, though we recognize the inherent limitations of this approach.

In summary, we do not claim that the models presented here are capable of predicting future market outcomes. Rather, we are modestly attempting to apply some analytic rigor to an area that has been the subject of passionate debate without, however, generating much in the way of systematic analysis.

II. – MODELING FUTURE MARKETS

The underlying model used to quantify the benefits of interoperability expects a certain percentage of the components (by cost) to be interoperable. These component prices decrease more rapidly, therefore leading to increased sales. The general assumptions for the different markets modeled are outlined in Table 1. The subscripts for different variables follow these rules :

h : market type : b : broadcast ; c : cable ; d : display ; v : VCRs ;
 p : personal computers ; w : workstations
 i : year ; i = 1997 ... 1998 ... 2011
 j : phase : used in the broadcast market
 k : speed of adoption : used in the display market

We define the experience curve factor (ECF_h) based upon the experience curve (EC_h) we use for the different markets from the following property :

$$ECF_h = [\ln (EC_h) / \ln (2)] - 1 \quad (1)$$

This is consistent with the experience curve discussed in the previous section.

Table 1 - Assumptions of the modeled market's characteristics

Market	Percent Interoperable (PI_h) (1)	Non-Interoperable Cost, year 1 (NCh_1)	Experience Curve (EC_h)(2)	Price Elasticity (PE_h)
Broadcast	20%	*	85%	**
Cable	75%	\$225 (3)	85%	-1.5 (4)
Display	30%	\$1,300 (5)	90%	-1.19 (6)
VCRs	30%	\$800 (7)	85%	-1.0 (8)
Personal Computers	30%	\$3,333 (9)	80%	1.44 (10)
Workstations	20%	\$8,333 (11)	80%	-1.44 (12)

* dependent upon phase of adoption, see discussion later in this article.

** not necessary for our model.

- (1) Cripps (1993) and Wilson (1993).
- (2) Hax (1982) estimates a 70% experience curve for integrated circuits, 80% for air conditioners, and 90% for primary magnesium. Since displays (televisions) have the largest penetration of the markets modeled, we estimate a 90% experience curve while most other markets are estimated with an 85% experience curve. The personal computer and workstation market was assessed to be 80% since it is the markets with the largest potential and largest growth.
- (3) Liu (1991) helped supply the codec estimates while Jerrold (1994) helped estimates for set-top prices.
- (4) Rubinovitz (1993).
- (5) Estimated from Liu (1991).
- (6) Houthakker (1970).
- (7) Cripps (1993) and Pollack (1993) suggest a VCR price of \$2000 with an approximate mark-up of 2.5 times the cost; hence \$800 for a high resolution VCR.
- (8) This number is estimated since no good data could be found on this particular item, so we estimated it to be similar but more inelastic than television.
- (9) Wilson (1993) estimates that a high-resolution personal computer's price will be approximately \$10,000 and we estimate that 1/3 of the price is the cost of the unit, hence \$3,333.
- (10) Gordon (1989).
- (11) Wilson (1993) estimates a \$25,000 price for a high resolution workstation which translates to a \$8,333 cost given a mark-up of 3.
- (12) While Gordon (1989) estimates the price elasticity for computers, we expect the price elasticity for workstations to be similar since the distinction between the markets is blurring - see Pool's (1984) prediction of convergence of modes.

While the six markets modeled follow experience curves between 80 - 90%, it is assumed that the cost of interoperable parts follow the 70% experience curve and, therefore, follow some reduction factor (RFi). This reduc-

tion factor is characterized by the following formula (where NU is the number of non-interoperable units sold for a given market, h, for a given year, i):

$$RF_i = [(\sum(i)\sum(h)NU_{hi})/(\sum(h)NU_{h1})]^{(\log(0.7)/\log(2))} \quad (2)$$

The next variable estimated is the cost penalty associated with interoperable parts. The value for the model was 25% (ISF), implying that interoperable parts were 25 percent more costly than they would otherwise be. This cost reflects the increased time and money needed to design parts which are interoperable across markets.

Broadcast

The model assumes that the complete transition to local production and transmission of HDTV programming can be broken into five major stages. These are : Pass-Through of Network Programming, Limited Local Playback, Extensive Local Playback, Limited Production and Post Production and Full Conversion. Each phase costs an amount to the broadcaster as outlined in Table 2 (NC_{1j} ; j is the phase) with a certain number of components purchased (Z_j).

Table 2 - Broadcaster cost per phase (1)

Phase	Cost (NC _{1j})	Components (Z _j)
Phase 1	\$1.6M	31
Phase 2	\$0.5M	18
Phase 3	\$1.1M	11
Phase 4	\$6.2M	78
Phase 5	\$1.4M	12

(1) Data for broadcast station transition costs to HDTV are derived Kutzner (1991). The model uses the average cost of each transition stage as a proxy for the actual cost of that stage for any particular broadcast station.

The ACATS Planning Subcommittee - Working Party 5 estimates that once the HDTV allotments are made, 30 stations in markets 1-10 will begin conversion during the first year, 40 stations in markets 11-30 in the second year, and 80 stations in market 31-100 in the third year. (14) From this data, we arrive at the figures in Table 3, showing the number of stations going through the transition (BC_{ij} ; where i is the year and j is the phase).

From this data, we can calculate how many interoperable and non-interoperable components are sold as a function of time (note that the units sold is the same for an interoperable standard as for a non-interoperable standard):

$$NU_{bi} = IU_{bi} = \sum(j)(BC_{ij} * Z_j) \quad (3)$$

(14) FCC (1992b)

Table 3 - Number of broadcasters adopting high resolution systems by phase

	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
1997	30				
1998	40	30			
1999	80	40	30		
2000	350	80	40	30	
2001	450	250	80	40	30
2002	550	300	200	80	40
2003		350	250	100	80
2004		250	300	150	100
2005		150	250	200	150
2006		50	200	200	150
2007			100	100	150
2008			50	100	150
2009				100	150
2010				100	100
2011					100

Therefore the cost per year, per phase for a non-interoperable broadcast standard will be :

$$NC_{bij} = NC_{Ij} * [((\sum(i)BC_{ij})/BC_{ij})^{ECF_b}] \quad (4)$$

The cost per year, per phase for an interoperable broadcast standard will be :

$$IC_{bij} = [NC_{bij} * (1 - PI_b)] + [RF_i * NC_{Ij} * PI_b * (1 + ISF)] \quad (5)$$

The total cost per year paid by the broadcasters to adopt a non-interoperable standard will be :

$$NY_{bi} = \sum(j)(NC_{bij} * BC_{ij}) \quad (6)$$

For a interoperable standard, the cost to the broadcasters will be :

$$IY_{bi} = \sum(j)(IC_{bij} * BC_{ij}) \quad (7)$$

Cable

Although there was rapid growth in the 1980's for cable television service in the U.S., the growth has recently declined to 1% per year (GI). The current number of cable subscribers is 55.1 million (CS_{ij}). (15)

We assumed that as the cable television market grows, new stations begin to adopt digital television programming until full penetration is realized by 2011. The model uses the figures in Table 4 to forecast the penetration of digital television cable into the growing cable market (GC_{ij}).

We assume a growth of the cable industry which follows this equation :

(15) Warren Publishing (1994), p. 168.

Table 4 - Growth of high resolution cable systems (1)

Year	Growth of HR Cable
1997	.5%
1998	1.5%
1999	3%
2000	6%
2001	10%
2002	15%
2003	20%
2004	30%
2005	45%
2006	55%
2007	65%
2008	75%
2009	85%
2010	95%
2011	100%

- (1) The underlying basis for this table is the assumption that by the year 2011 all televisions will be able to receive high definition broadcasts since the FCC has plans to reclaim spectrum that isn't high definition at that time. The numbers were estimated to reflect slow adoption of high resolution systems at first and more rapid adoption as the majority of broadcast stations began their high definition transition.

$$CS_i = CS_1 * (1+GI)^i \quad (8)$$

Where the cost for a non-interoperable cable standard will be :

$$NC_{ci} = NC_{c1} * [((\sum(i)NU_{ci})/NU_{c1})^{ECF_c}] \quad (9)$$

For an interoperable standard, the cost will be :

$$IC_{ci} = [NC_{ci} * (1 - PI_{ci})] + [RF_i * NC_{c1} * PI_{ci} * (1+ISF)] \quad (10)$$

The annual sales for a non-interoperable cable standard will be :

$$NU_{ci} = [CS_i * GC_i] - [CS_{(i-1)} * GC_{(i-1)}] \quad (11)$$

The annual sales for an interoperable standard will be :

$$IU_{ci} = [1 + (PE_c * ((IC_{ci} - NC_{ci})/NC_{ci}))] * NU_{ci} \quad (12)$$

Display

The display segment is the largest consumer of interoperable parts in the model. Annual sales of color televisions currently exceed 20 million units. Data from the ACATS Working Party 5 hypothesize penetration rates based on high perceived viewer value and on low perceived viewer value as

outlined in Table 5 (SC_{ik} ; where k is either f : fast ; s : slow). (16) For example, the fast case estimates that in 1998 there will be approximately an 86% increase in the sales of digital television displays from the previous year while the slow case estimates a 76% increase in sales over the previous year. In the interests of simplicity, this article averages the two penetration rates for its calculations. In the FCC (1992b) report, the number of units sold in year one is 473,000 (NU_{d1f}) for the fast case and 300,000 (NU_{d1s}) for the slow case. Once again, these number are averaged for this analysis.

Table 5 - Fast and slow adoption of HDTV

Year	Fast (f)	Slow (s)
1998	85.84%	76.33%
1999	61.77%	50.66%
2000	52.39%	50.69%
2001	44.62%	41.88%
2002	44.54%	48.65%
2003	39.47%	35.33%
2004	39.79%	35.41%
2005	40.23%	34.38%
2006	37.72%	30.04%
2007	25%	25%
2008	20%	20%
2009	15%	15%
2010	10%	10%
2011	5%	5%

Therefore the total cost for a non-interoperable display standard will be :

$$NC_{di} = NC_{d1} * [((\sum(i)NU_{di})/NU_{d1})^{ECF_d}] \quad (13)$$

For an interoperable standard, the cost will be

$$IC_{di} = [NC_{di} * (1 - PI_d)] + [RF_i * PI_d * NC_{d1} * (1 + ISF)] \quad (14)$$

The annual sales for a non-interoperable display standard will be :

$$NU_{di} = 0.5 * \sum(k)[NU_{d1k} * \prod(i)(1 + SC_{ik})] \quad (15)$$

The annual sales for an interoperable standard will be :

$$IU_{di} = [1 + (PE_d * ((IC_{di} - NC_{di})/NC_{di}))] * NU_{di} \quad (16)$$

(16) Data for these two scenarios was derived from FCC (1992b). In order to simplify the model and as a result of cost data that has become available since the publication of the FCC (1992b) document, the model assumes an initial price of \$3000 for an HDTV display. This corresponds to high initial price according to the FCC (1992b) document. However, it should be noted that a scalable standard will enable the production of lower cost displays that decode less than the full digital data stream with a corresponding reduction in resolution. See also U.S. Congress (1996).

VCR

The model assumes that the market for digital VCRs depends on the size of the market for digital television displays. The model operates on the assumption described in the final report of ACATS-PS-WP/5, where the total revenue from the sale of HDTV VCRs will be roughly 6 percent of the revenue for digital television displays. (17) From this data, the model assumes VCR sales will be a percentage of the display sales in accordance with Table 6 (PDRi) :

Table 6 - Growth of the high resolution VCR market (1)

Year	VCR Market (% of display market)
1997	5.5%
1998	5.5%
1999	7%
2000	7%
2001	8.5%
2002	8.5%
2003	10%
2004	10%
2005	11.5%
2006	11.5%
2007	13%
2008	13%
2009	15%
2010	15%
2011	15%

- (1) The basis for these numbers is an estimate from the current television and VCR markets where the revenues from VCR sales are 15% of the revenues for television sales (this is an assumed steady-state ratio for the high resolution market as well)

Therefore the total cost for a non-interoperable VCR standard will be :

$$NC_{vi} = NC_{vi} * [((\sum(i) NU_{vi}) + NU_{vi})^{ECF_v}] \quad (17)$$

For an interoperable VCR, the cost will be

$$IC_{vi} = [NC_{vi} * (1 - PI_v)] + [RF_i * PI_v * NC_{vi}] * (1 + ISF) \quad (18)$$

The annual sales for a non-interoperable VCR standard will be :

$$NU_{vi} = (NC_{di} * NU_{di}) * (PDR_i / NC_{vi}) \quad (19)$$

The annual sales for an interoperable VCR will be :

$$IU_{vi} = [1 + (PE_v * ((IC_{vi} - NC_{vi}) / NC_{vi}))] * NU_{vi} \quad (20)$$

(17) FCC (1992b)

Personal Computers

The growth of the digital multimedia personal computer market depends upon the growth of the regular personal computer market. The model uses an estimate for the size of the current personal computer (PC) market to incur \$13.9 Billion in cost (M_{p0}). (18) Since the Data Analysis Group (1993) estimates a compound annual growth rate of 8 percent for the personal computer industry between 1995-1998, we estimate the growth of the personal computers as follows in Table 7 (MG_{pi})

Table 7 - Growth of the high resolution computer market

Market	Personal Computer Market Growth
1997 - 2000	8.3%
2001 - 2005	5%
2006 - 2011	2%

The multimedia personal computer market will be a percentage of the regular personal computer market and is assumed to follow the adoption scheme outlined in Table 8 (PM_{pi}).

Table 8 - Percentage of personal computer sold that high resolution (1)

Market	% High Resolution PC
1997, 1998	5%
1999, 2000	10%
2001, 2002	15%
2003, 2004	20%
2005 - 2007	25%
2008 - 2011	30%

(1) Adoption schedule was derived from Cohen : 1993

Therefore the total cost for a non-interoperable multimedia personal computer will be

$$NC_{pi} = NC_{p1} * [((\sum(i)NU_{pi})/NU_{p1})^{ECF_{p1}}] \quad (21)$$

For an interoperable multimedia personal computer, the cost will be :

$$IC_{pi} = [NC_{pi} * (1 - PI_p)] + [RF_i * PI_p * NC_{p1} * (1 + ISF)] \quad (22)$$

(18) Data Analysis Group (1993) assumes that the market is currently \$41.7 billion of which we estimate about 1/3 is cost to manufacture personal computers.

The annual sales for a non-interoperable multimedia personal computer will be :

$$NU_{pi} = [\prod(i)(1 + MG_{pi})] * M_{p0} * PM_{pi} / NC_{pi} \quad (23)$$

The annual sales for an interoperable multimedia personal computer will be :

$$IU_{pi} = [1 + (PE_p * ((IC_{pi} - NC_{pi}) / NC_{pi}))] * NU_{pi} \quad (24)$$

Workstations

The current workstation market is assumed to incur \$4.667 Billion in cost (M_{w0}) (19). Although this market is expected to grow annually at 14.5% by the Data Analysis Group (1993), we assume that growth rates will decrease in future years, as shown in Table 9 (MG_{wi}).

Table 9 - Growth of the high resolution workstation market

Year	Workstation Market Growth
1997 - 2000	14%
2001 - 2005	10%
2006 - 2011	6%

Like the model for the personal computer, the digital multimedia workstation market will grow as a function of the regular workstation market. The multimedia workstation market is modeled in accordance with Table 10 (PM_{wi}).

Table 10 - Percentage of workstations sold that are high resolution (1)

Market	% High Resolution Workstation
1997, 1998	15%
1999, 2000	20%
2001, 2002	25%
2003, 2004	30%
2005 - 2007	35%
2008 - 2011	40%

(1) Adoption schedule was derived from Cohen (1993).

Therefore the total cost for a non-interoperable multimedia workstation will be :

$$NC_{wi} = NC_{w1} * [(\sum(i) NU_{wi}) / NU_{w1}]^{ECFw} \quad (25)$$

(19) Data Analysis Group (1993) estimates the workstation market at \$14 billion which we approximate 1/3 of that is cost; hence \$4.667 billion.

For an interoperable multimedia workstation, the cost will be :

$$IC_{wi} = [NC_{wi} * (1 - PI_w)] + [RF_i * PI_w * NC_{wi} * (1 + ISF)] \quad (26)$$

The annual sales for a non-interoperable multimedia workstation will be :

$$NU_{wi} = [\prod(i)(1 + MG_{wi})] * M_{w0} * PM_{wi} / NC_{wi} \quad (27)$$

The annual sales for an interoperable multimedia workstation will be :

$$IU_{wi} = [1 + (PE_w * ((IC_{wi} - NC_{wi}) / NC_{wi}))] * NU_{wi} \quad (28)$$

III. – MODEL RESULTS

Tables 11 through 15 summarize the results from the model.

*Table 11 - Cost of broadcasters to transition
(million of \$) (NY_{bi} and IY_{bi})*

Year	Non-Interoperable Broadcast	Interoperable Broadcast
1997	\$48	\$50
2001	\$694	\$621
2006	\$781	\$659
2011	\$59	\$49

*Table 12 - Sale of high resolution systems
(million of \$) (NU_{bi} and IU_{bi})*

Year	Cable		Display		VCR		Personal Computer		Worstation	
	Non- Interop	Interop	Non- Interop	Interop	Non- Interop	Interop	Non- Interop	Interop	Non- Interop	Interop
1997	0.278	0.231	0.387	0.352	0.037	0.032	0.226	0.201	0.096	0.089
2001	2.35	3.06	2.42	2.93	0.480	0.539	2.50	2.77	0.639	0.701
2006	6.36	9.32	12.6	16.2	4.59	5.41	9.67	11.7	2.50	2.90
2011	3.80	5.85	25.1	32.8	14.7	17.6	18.3	22.9	5.57	6.59

*Table 13 - Cost of high resolution systems
(NC_{bi} and IC_{bi})*

Year	Cable		Display		VCR		Personal Computer		Worstation	
	Non- Interop	Interop	Non- Interop	Interop	Non- Interop	Interop	Non- Interop	Interop	Non- Interop	Interop
1997	\$225	\$267	\$1300	\$1398	\$800	\$860	\$3333	\$3583	\$8333	\$8750
2001	\$110	\$73	\$851	\$701	\$364	\$320	\$1205	\$1114	\$3392	\$3164
2006	\$73	\$35	\$634	\$483	\$200	\$164	\$643	\$551	\$1884	\$1675
2011	\$63	\$25	\$526	\$390	\$135	\$108	\$451	\$371	\$1293	\$1128

IV. – ANALYSIS OF RESULTS

All six markets gain economic benefits by adopting an interoperable HDTV standard. Although future benefits may seem nebulous in the face of concrete increased short-term costs, these losses are recouped in the not-very-long term period of three years, as a result of greater accumulated production of interoperable parts which, in turn, experience a greater decrease in cost as a result of accumulated production than non-interoperable parts. In addition, it is evident that tremendous benefits larger than costs are palpable – in enabling new businesses, applications, and services to emerge – with broad economic and social benefits.

The model estimates that over a 15 year period, these industries will spend \$241 billion in manufacturing costs. These industries would reduce the average cost by 21 percent if they were to build interoperable rather than non-interoperable equipment. (20) The model estimates that these industries will – collectively – sell 27 percent, or 115 million, more units if the equipment they build is interoperable. Separately, the model shows that all markets benefit from an interoperable standard. The broadcast market has a 17% cost advantage if it adopts an interoperable standard. The cable industry benefits the most by getting a 45% increase in the total number of units sold and a reduction in cost of 49%. The display and VCR markets increase sales by 29% and 19% and reduce average cost by 24% and 19% respectively. Finally the model estimates sales increases of 22% and 16% for the computer and workstation markets while reducing average cost by 15% and 12% respectively.

In Tables 11 through 15, the costs were aggregated into a net present value at year 1 – 1997 in the model. A discount rate of 10.2% was used and the cost was normalized by the total sales over the 15 year period examined. (21) Therefore, the benefit of an interoperable standard is outlined in Table 16.

Table 14 - Net present value (NPV) of the interoperate cost saving per unit

Market	NPV interoperable cost savings per unit
Broadcast	\$310.700
Cable	\$17.30
Display	\$56.46
VCRs	\$11.44
Personal Computers	\$41.63
Workstations	\$91.21

(20) This calculation was done by dividing the average cost for the sum of all interoperable units by the average cost for the sum of all non-interoperable units.

(21) The discount rate of 10.2% is an estimate from Bruce Jacobson and his experience with SNET

To determine how sensitive some variables are to our results, the net present value calculation used for Table 16 is used. Tables 17 through 21 show the results for sensitivity analysis for discount rate, the interoperable savings factor (ISF), percent interoperable (IP_h), experience curve factor (EC_h), and the experience curve factor for integrated circuits respectively.

Table 15 - Sensitivity analysis for the discount rate

Market	5%	10.2% (baseline)	20%	30%	40%
Broadcast	\$440,800	\$310,700	\$174,900	\$106,500	\$69,590
Cable	\$25.53	\$17.30	\$9.33	\$5.65	\$3.80
Display	\$89.32	\$56.46	\$27.10	\$14.99	\$9.46
VCRs	\$18.79	\$11.44	\$5.07	\$2.56	\$1.47
Personal	\$61.93	\$41.63	\$22.55	\$14.03	\$9.80
Computers					
Workstations	\$135.20	\$91.21	\$50.16	\$31.96	\$22.95

The sensitivity analysis indicates that an interoperable digital television standard will be beneficial even with variations in most variables. Over the range examined, variations in the discount rate, interoperable savings factor (ISF), and percent interoperable by market (PI_h) result in interoperability benefits. Perhaps most interesting is the interoperability savings factor (ISF) variable as seen in Table 18. Even when the increase in interoperable components was double the price on non-interoperable components (i.e. ISF = 100%), an interoperable standard is still more beneficial over the long run. This conclusion is most meaningful to firms that behave with long-term strategies because of the model's fifteen year projections. Firms that are more short-sighted may focus on the limited initial benefits of interoperability and may limit long-run, consumer and producer welfare. Therefore, proactive steps to ensure interoperability may be necessary to realize the estimated benefits.

Table 16 - Sensitivity analysis for interoperability savings factor (ISF)

Market	5%	25% (baseline)	50%	75%	100%
Broadcast	\$339,600	\$310,700	\$274,600	\$238,500	\$202,400
Cable	\$18.78	\$17.30	\$15.58	\$14.00	\$12.58
Display	\$58.64	\$56.46	\$53.81	\$51.28	\$48.85
VCRs	\$12.55	\$11.44	\$10.08	\$8.74	\$7.42
Personal	\$47.35	\$41.63	\$34.85	\$28.49	\$22.66
Computers					
Workstations	\$100.50	\$91.21	\$80.02	\$69.41	\$59.39

The experience curve for the industries and integrated circuits is the most sensitive variable as seen in Table 20. It shows that a non-interoperable digital television standard will be beneficial if the experience curve for integrated circuits is approximately 0.77 or greater or if the experience curve factor for the VCR, personal computer, and workstation markets falls approximately

7% less than its baseline numbers. Perhaps the most insightful conclusions from this sensitivity analysis is that as individual experience curve factors decrease for a particular industry (i.e. the market is more dynamic and in the beginning part of its diffusion) the benefit of an interoperable standard also decreases. This conclusion is not unexpected. Some argue that rapidly advancing technologies should not strive for standards and interoperability because of market and technical uncertainty. In these cases, a competitive market may be better for long-run interoperability than a premature drive to standardization but this analysis is beyond the scope of this article.

Table 17 - Sensitivity analysis for the percent interoperable (PI_h)

Market	-10%	-5%	0 (baseline)	+5%	+10%
Broadcast	\$155,300	\$233,000	\$310,700	\$388,400	\$466,000
Cable	\$15.07	\$16.19	\$17.30	\$18.42	\$19.53
Display	\$37.89	\$47.20	\$56.46	\$65.67	\$74.84
VCRs	\$7.67	\$9.56	\$11.44	\$13.32	\$15.20
Personal	\$28.19	\$34.95	\$41.63	\$48.21	\$54.73
Computers					
Workstations	\$36.44	\$69.01	\$91.21	\$113.10	\$134.70

Table 18 - Sensitivity analysis for the experience curve (EC_h)

Market	-10%	-5%	0 (baseline)	+5%	+10%
Broadcast	\$133,800	\$213,000	\$310,700	\$429,900	\$574,400
Cable	\$3.47	\$9.35	\$17.30	\$28.12	\$42.72
Display	\$18.59	\$34.43	\$56.46	\$87.12	\$129.50
VCRs	-\$1.65	\$3.61	\$11.44	\$23.85	\$43.52
Personal	\$14.22	\$11.71	\$41.63	\$82.62	\$140.70
Computers					
Workstations	-\$5.79	\$38.5	\$91.21	\$160.90	\$255.80

Table 19 - Sensitivity analysis for the experience curve for integrated circuits

Market	60%	65%	70% (baseline)	75%	80%
Broadcast	\$399,700	\$362,400	\$310,700	\$240,000	\$144,300
Cable	\$22.79	\$20.57	\$17.30	\$12.51	\$5.44
Display	\$65.39	\$61.94	\$56.46	\$47.90	\$34.72
VCRs	\$16.15	\$14.38	\$11.44	\$6.67	-\$1.00
Personal	\$66.87	\$57.27	\$41.63	\$16.09	-\$27.12
Computers					
Workstations	\$133.20	\$117.40	\$91.21	\$48.38	-\$22.22

V. – CONCLUSION

Standards development for digital television may follow the systems or intermodal models outlined by Kavassalis and Solomon (1996). We have shown here that economic modeling of these two scenarios shows that there

may be industrial economic benefits realized in a greater number of units sold and a lower unit cost if the «intermodal» or interoperable scenario is adopted. This is a result from the economic model described in this article which quantifies the benefits of accumulated production across six converging industries.

Developments in Europe and Japan in the 1990s suggest that the global imaging communities have recognized that digital technology is the basis for future digital television systems. In creating an interoperable standard for HDTV, the FCC may give firms participating in the U.S. market a head start in developing components of systems that could serve the entire globe. As the world's largest producer of programming material, the U.S. has a tremendous interest in creating a standard that allows export and exchange of video and multimedia text and graphics material on terms as free from technical and political barriers as possible. While costs have only been calculated for the U.S. market, we expect similar results would be obtained by European or Japanese analysts for their respective markets. Although interoperability enables a lower cost transition from current television standards to a Global Information Infrastructure for broadcasters, equipment manufacturers and consumers alike, the business models which show how firms may profit in this new environment have yet to be developed.

Corporate strategy options will be significantly affected by an open, interoperable digital television standard. Interoperability poses a significant challenge as cost competition becomes less of a viable option for all industries. However, the opportunities to differentiate or focus a product on one consumer segment will be greatly enhanced as a result of an interoperable standard. Interoperability does *not* preclude market segmentation or product differentiation. The ability to connect to and perhaps to interact with new sources of programming presents the bravest new world to both programmers and manufacturers developing new equipment, distribution systems, value added services, and program options. These services, enabled by interoperability, offer the opportunity for firms to differentiate products both in terms of functionality and resolution in a way that limits price competition. An interoperable, digital television platform for the Global Information Infrastructure can be achieved if industry, policy makers and the public recognize the opportunity and accept the inherent risk in adopting a visionary approach to the problem of interoperability standards. The promise of networked multimedia for entertainment, information, education, and health applications by public organizations, private firms, and individuals is sufficient to suggest the short-term transition costs will be worth bearing.

In this paper, we have demonstrated the economic logic for developing standards for digital television interoperability and not simply for a digital television system. Whether logic will prevail over politics and corporate strategies in selecting digital television standards, remains to be seen.